Prince Edward Viaduct –100 Years of Service

Oleksiy Chernoloz, Department of Civil and Mineral Engineering, University of Toronto, 35 Saint George St., Toronto, ON, M5S 1A4, Canada, alex.chernoloz@mail.utoronto.ca

Karl Peterson, Department of Civil and Mineral Engineering, University of Toronto, 35 Saint George St., Toronto, ON, M5S 1A4, Canada, karl.peterson@utoronto.ca

INTRODUCTION

The Prince Edward Viaduct, also known as the Bloor Street Viaduct, is a truss arch bridge in Toronto, connecting the central and eastern parts of the city, separated by the Don River Valley. The project was a subject of heated public debate, and four referenda were held on the construction of the viaduct. Rejected in 1910, 1911 and 1912, it was finally approved in 1913, after the project underwent significant improvements in its alignment, material use, and aesthetic appearance. The bridge is noted for the forward-thinking “double-deck” design with the lower deck below the roadway to allow for future subway construction. The bridge was completed in 1918, creating a major thoroughfare and facilitating city growth. The Bloor-Danforth subway line (Line 2), crossing the bridge, was opened in 1966. Today the viaduct with a span of 494 m is one of the most recognizable landmarks and one of the most critical pieces of transport infrastructure in Toronto. This extended abstract presents the history of the project, discusses the design and construction of the bridge, focusing on the concrete structure, and makes a rough estimate of CO_2 absorbed over its lifetime.

BRIEF HISTORY

On the turn of the twentieth century, the population of Toronto was undergoing dramatic growth, rising from 44,821 in 1861 to 208,040 in 1901, fuelled in large part by pre-war immigration from Europe [1]. Many working-class immigrants settled on the east side of Don River ravine [2], including the village of Riverdale (annexed by the City of Toronto in 1889), Chester and East York (annexed in 1909). The Toronto Railway Company (TRC) in 1891 won a 30-year exclusive right to run streetcars on the streets of Toronto, which proved highly controversial. The city would later sue the company to expand its service to other areas of the growing city, but lost [3]. Commuters from eastern suburbs had to travel south on overcrowded TRC streetcars and use either Gerrard or Queen Street bridges, taking a long detour and creating serious congestion. The future mayor, Horatio Hocken, proposed to break the virtual monopoly of the TRC by building subway lines (‘tubes’), like in London, Paris, New York, and Boston. In 1910 the mayor and the Board of Control commissioned the New York engineering firm of Jacobs and Davies to prepare a report on this topic. The report, “Street Railway Transportation in the City of Toronto”, prepared by engineer James Forgie, proposed a subway scheme, which included a double-decker viaduct, spanning the Don River valley. The project attracted significant public debate, related to the cost and who will bear it, as well as the route, design, and material of the bridge. Opponents of the bridge pointed out that the townships east of the Don River will benefit from the viaduct more, but the city will bear the largest expense [4]. The original project with an estimate of CA$759,000, devised by the city engineer C.H. Rust, recommended a single mile-long bridge, crossing both Rosedale Ravine and Don River Valley; well-to-do residents of adjacent Rosedale neighbourhood were strongly against it.

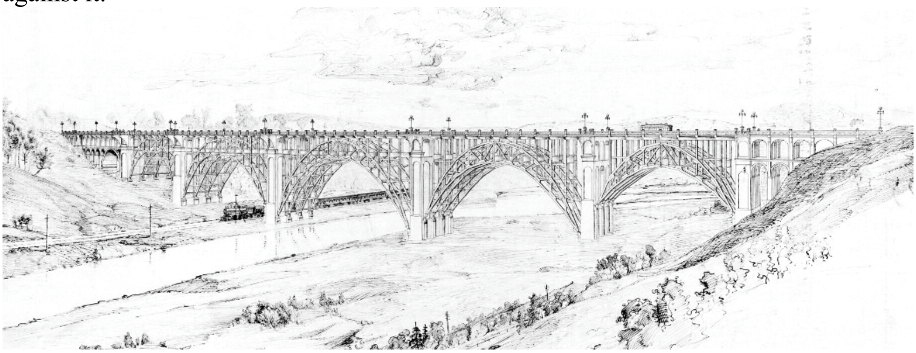

Figure 1: Perspective Study of Don Bridge, 1913. City of Toronto Archives, Fonds 89, File 6, Item 1

The Commissioner of Public Works and the city engineer of Toronto, R.C.Harris, who replaced C.H. Rust, insisted upon a lower deck of the bridge for the future public rail transport, which increased the cost of the project and attracted opposition. Lastly, the city council was divided between building a concrete or steel structure, and was subjected to intense pressure from competing industries. Three initial iterations of the project were rejected by voters in 1910, 1911 and 1912. The final design was reached after many compromises and decisively won in 1913—voters approved the issuance of debentures of almost CA$2,480,000 for the new project, which was split into three sections to minimize encroachment on the Rosedale ravine, and reached the compromise on the bridge design—a double-decker, largely steel structure on concrete piers. The Designing and Construction Engineer Thomas Taylor summed up the approval in the following way: "The remarkable increase in these estimates [from CA$ 769,000 to 2,480,000] is due to the fact that each of the two latter schemes was greatly superior to its predecessor with respect to capacity and appearance. The verdicts rendered ... indicate, on the part of the Toronto public, a growing appreciation of civic improvements".

DESIGN AND CONSTRUCTION

The final design was completed by Taylor and the consulting architect Edmund Burke. In 1912 City staff undertook an extensive geotechnical investigation which discovered that soil cover in the valley reached 30-40 ft and was not competent enough to support the load of the viaduct. It was decided that the topsoil would be excavated and the central piers of reinforced concrete placed on the bedrock (alternating layers of limestone and shale). Design of the bridge and position of the piers had to accommodate the Don River, Don View Avenue, and two railway right-of-ways, plus the consulting architect insisted on maintaining the symmetry of design. The Don Valley Viaduct has a main span of 85.8 m (281.5 ft), 39.6 m (130 ft) above the river, two flanking spans of 73.2 m (240 ft), and 48.2 m long (158 ft) end spans. The total length of the bridge (with piers and approaches) is 494 m (1,620 ft). For the placement of concrete, five mixers were situated next to the piers; to facilitate the pour of tall piers, the contractors erected elevator towers with hoppers and steel chutes. A total of 13 pairs of 6 in * 12 in concrete cylinders were cast, moist-cured and tested at 30 and 90 days respectively [4]. A summary of the tests is presented in the following Table 1 (values converted from psi to MPa).

Table 1: Compressive strengths of concrete cylinders, Rosedale Section [4].

Mix proportions	Location (elevations listed in ft above mean sea level)	1 month		3 months	
		psi	MPa	psi	MPa
1:2½:5	West Pier, footing N	2099	14.5	2376	16.4
		1690	11.7	2376	16.4
	West Pier, footing S	2733	18.8	3241	22.3
		2895	20.0	3004	20.7
	West Pier, elev. 315 ft	1846	12.7	2366	16.3
		2868	19.8	1838	12.7
	East Pier, elev. 290 ft	1979	13.6	2715	18.7
		1744	12.0	3109	21.4
	Center Pier, elev. 290 ft	2243	15.5	2001	13.8
		2179	15.0	2591	17.9
	West Pier, elev. 340 ft	2827	19.5	3042	21.0
		2851	19.7	3309	22.8
	Cross wall, west approach	1873	12.9	1805	12.4
		1931	13.3	3037	20.9
	Center Pier elev. 310 ft	2260	15.6	2360	16.3
		1799	12.4	3299	22.7
	East Pier elev. 310 ft	1670	11.5	3021	20.8
		2250	15.5	2138	14.7
	East Pier elev. 330 ft	1235	8.5	2967	20.5
		1149	7.9	2661	18.3
	Center Pier elev. 340 ft	1962	13.5	2200	15.2
		1931	13.3	3046	21.0
1:2¾:5½	East Pier, elev. 280 ft	2783	19.2	3394	23.4
		2749	19.0	3299	22.7
	Center Pier, elev. 280 ft	3238	22.3	3394	23.4
		2681	18.5	3394	23.4

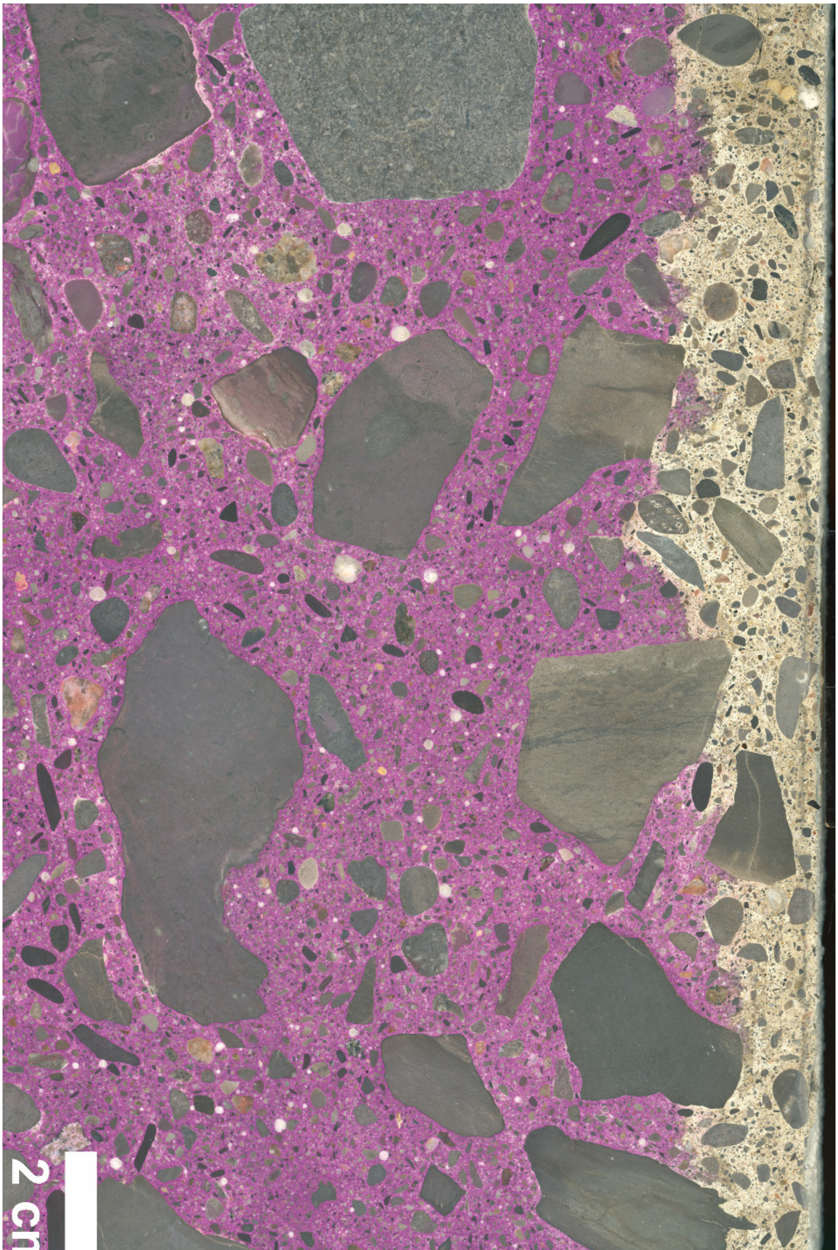

Figure 2: Phenolphthalein stained slab, exterior atmosphere-exposed surface at top.

CORE IMAGE ANALYSIS

A 29.5 cm dia. core was recovered from the base of the northwest abutment wall, and slabbed and lapped. The lapped surface was scanned as-is with a flatbed scanner at a resolution of 10 µm/pixel (2,540 dpi) in 24-bit RGB color. This process was repeated after phenolphthalein staining, and after painting this surface black and pressing white wollastonite powder into the air voids. A portion of the phenolphthalein-stained surface image is shown in Figure 2, from which the carbonation depth was measured to be the range of 11 to 32 mm, with an average depth of 21 mm. By aligning the three scanned images, and performing a multispectral classification on the stacked images, the volume percentages of aggregate, paste, and air were measured at 62.7%, 35.8%, and 1.5% respectively. This paste volume is higher than would be expected, based on the mix proportions from Table 1. The volume estimates were obtained from the non-carbonated portion of the concrete, where the color contrast of the paste allowed for easier spectral distinction from the aggregate. The paste content immediately adjacent to the formwork surface may be even higher due to the wall effect [6].

AN ESTIMATE OF ABSORBED CO_2

According to calculations by Pade and Guimaraes [7], about 75% of the CaO originally present in cement clinker is converted to $CaCO_3$ when concrete is fully carbonated. The portland cement used in the viaduct was produced by the Canada Cement Company [8]. The company formed in 1909 through the consolidation of nine different portland cement plants distributed throughout Ontario and Quebec [9]. The identity of the individual plant (or plants) that produced the cement used in the viaduct has not yet been determined, nor have any wt. % oxide cement mill reports been obtained from any Canadian producers that overlap with the time period when the viaduct was built. However, Eckel's 1905 summary of the North American cement industry [10] reports CaO contents from eighty portland cement producers in the United States, covering a range of 58.0-65.4 wt. % CaO, with an average of 62.5 wt. %. At the time, portland cements were not routinely interground with limestone, so the only major source of CaO other than the clinker itself would be the calcium sulfate addition. Eckel places this in the range of 2-3%, occurring as either "crude gypsum" "calcined plaster" or "dead-burnt (anhydrous) plaster" [10]. Depending on the source of calcium sulfate, its purity, and the amount added, it puts the clinker CaO content from Eckel's summary somewhere in the range of 57.6-64.5%.

Two other remaining important pieces of information are required to come up with an estimate of CO_2 consumed through carbonation. First, the surface area of the concrete portions of the bridge, and second the *w/cm* ratio. Although architectural drawings of the viaduct are maintained by the City of Toronto Archives, access to them is highly restricted. As an alternative, a surface area estimate was obtained from a 3D model of the Don Valley section of the viaduct [11]; the model was verified against the dimensions of the bridge and was found to be in good agreement with the original structure. Based on this model, the surface area of exposed concrete is approximately

28,000 m². To date, no work has been conducted to try and quantify the *w/cm*. But, assuming a *w/cm* in the range of 0.5 to 0.6, a cement density of 3150 kg/m^3, a paste volume of 35.8%, a cement clinker CaO content of 62%, a carbonation depth of 21 mm, and Pade and Guimaraes' 75% conversion value, an estimated 84 to 94 metric tons of CO_2 have been absorbed over the life of the viaduct. To put this in perspective, in 2013, the per capita CO_2 emissions in Ontario were estimated at 12.6 metric tons [12].

REFERENCES

[1] City of Toronto Archives, "Toronto's History: Popular Topics," [Online]. Available: https://www.toronto.ca/city-government/accountability-operations-customer-service/access-city-information-or-records/city-of-toronto-archives/using-the-archives/research-by-topic/toronto-history-faqs/.
[2] A. Murnaghan, "The city, the country, and Toronto's Bloor viaduct, 1897-1919.," Urban History Review/Revue d'histoire urbaine, vol. 42(1), pp. 41-50, 2013.
[3] M. Osbaldeston, Unbuilt Toronto: A history of the city that might have been, Dundurn Press, Toronto, 2008.
[4] "The Proposed Bloor Street Viaduct," Globe, July 1907.
[5] T. Taylor, "The Bloor Street Viaduct, Toronto, Ontario.," The Journal of the Engineering Institute of Canada., vol. 2, pp. 485-498, 1919.
[6] P.C. Kreijger, Skin of concrete - composition and properties, Materiaux et constructions, vol. 17, no. 100, pp. 275-283, 1984.
[7] C. Pade, M. Guimaraes, "The CO_2 uptake of concrete in a 100 year perspective," Cement and Concrete Research, vol. 37, no. 9, pp. 1348-1356, 2007.
[8] "Steel joined on Bloor Street Viaduct, Toronto—Another stage in the completion of Big Bridge—Contractors are ahead of schedule—Rosedale section practically finished—A review of past progress—Steel erection methods," The Contract Record, May 9, 1917, pp. 412.
[9] D.F. Hewitt, The Portland Cement Industry in Ontario, Industrial Mineral Report No. 25, Ontario Department of Mines, 1968.
[10] E.C. Eckel, Cements, limes, and plasters; their materials, manufacture, and properties, 1st Ed., New York, Wiley, 1905.
[11] Wyliepoon, "Prince Edward Viaduct (Bloor Viaduct)," 22 03 2014. [Online]. Available: https://3dwarehouse.sketchup.com/model/be36e5d190e4a26be9ef79508f816d93/Prince-Edward-Viaduct-Bloor-Viaduct?hl=en. [Accessed 01 05 2019].
[12] P. Boothe, F.-A. Boudreault "By the numbers: Canadian GHG Emissions" Lawrence National Centre for Policy and Management, Ivey Business School, Western University, London, Ontario, 2016.